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Research Article

Forest patches as important bird habitats in Malaysia's large-scale infrastructure development areas

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Abstract

The high demand for hydroelectric power to support electricity in rural areas of Malaysia drives the construction of dams. The development of large-scale dams threatens forest-dependent avian species due to habitat loss and fragmentation. Although many recent dam projects incorporate sustainable concepts for monitoring and managing wildlife, there is a lack of studies conducted during the development phase. This study evaluated avian species diversity across various habitats along a dam construction gradient, including recently disturbed forests, agricultural-forest patches and mosaic habitats. We conducted surveys using point count observations and mist-netting across six sampling sites over a 24-month period. A total of 120 bird species representing 40 families were recorded across the study area. Species richness was highest in agricultural–forest patches (78 species), followed by recently disturbed forests (65 species) and mosaic habitats (57 species). Hill numbers analysis similarly showed that agricultural–forest patches had the greatest overall diversity and the highest number of forest-dependent species. Feeding-guild patterns showed that omnivores dominated agricultural–forest patches and recently disturbed forests, while insectivores formed the largest proportion of the community in mosaic habitats containing embedded forest patches. Such findings highlight the importance of maintaining forest patches within homogeneous or degraded habitats, including agricultural and mosaic landscapes, as these remnants can continue to support substantial bird communities when properly managed. By implementing such sustainable management practices, the negative impacts of large-scale development projects on forest-dependent avian populations can be mitigated.

Key words: Agricultural, avifauna, hydrodam, mosaic habitats, recently disturbed forests, remnant forests

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Introduction

The rising demand for hydroelectric power in Malaysia has driven the construction of new dams, including the large-scale Nenggiri hydroelectric dam, which is currently under construction in the State of Kelantan. While such projects

have benefits, such as preventing flooding, providing renewable energy and the potential to transform the socio-economic conditions of the population (Hossain et al. 2018), the opening of forest areas for the construction of dams and high rates of ensuing logging activity lead to the loss of wildlife (Irving et al. 2018; Zainol et al. 2020; Nasruddin-Roshidi et al. 2021). Dam construction has a significant environmental impact due to the decreases in forest cover that result from deforestation and habitat fragmentation (Tang et al. 2010; Andriolo et al. 2013). Therefore, it is important to identify the habitat surrounding the dam project and the species of wildlife within the dam area.

The construction of dams can precipitate a cascade of environmental changes, including the establishment of logging road networks, indigenous settlements, construction zones and vast logged regions designated for reservoirs, all of which will inevitably fragment and isolate the available habitats within the landscape. Before the inundation phase of large hydroelectric reservoirs, there may be considerable effects on aquatic and terrestrial biodiversity due to habitat loss and fragmentation along with alterations in the physical and chemical characteristics of the environment (Brown et al. 2024). During the construction phase before flooding occurs, the development of large dams can obstruct feeding and reproductive habitats and interfere with the dispersal and movement patterns of vertebrate populations across the landscape (Fimbel et al. 2001; Kleinschroth and Healey 2017). The effects of habitat loss may diminish biodiversity by altering competitive and predator-prey dynamics; this often favours generalist species and, thus, can affect the long-term stability of natural communities (Brose et al. 2017).

Numerous avian species are sensitive to habitat loss, resulting in decreases in abundance and species richness immediately after anthropogenic disturbances. Birds, as indicators of forest habitat quality, play an important role in maintaining ecological balance (Egwumah et al. 2017; Grande et al. 2018; Puan et al. 2020; Kour and Singh 2023). Therefore, it is crucial to conduct bird studies in the areas remaining after habitat fragmentation caused by the development of dams and the associated logging activities. Common approaches employed by researchers for studying bird communities include point count, mist-netting and analyses of how species exhibit geographical variation in response to changes in the nature and structure of habitats (Eglington et al. 2012; Gardali et al. 2017; Tripathy et al. 2023).

In recently disturbed forests, larger forest areas with high ecosystem integrity provide ideal foraging niches and shelter for many bird species (Grantham et al. 2020; Mansor et al. 2020a; Khiruddin et al. 2025). Forested areas can maintain conditions in terms of adequate food resources, suitable habitat structure and diversity of vegetation. Studies of the remaining forests in Sarawak have shown that, for hornbills, the area should be at least 50,000 hectares and that this can either be a single block or a cluster of virtually contiguous blocks forming a forest complex (Jaafar et al. 2020; Wee et al. 2024). Meanwhile, forest–agricultural landscape habitat refers to forested areas situated next to agricultural lands, consisting of remnant patches of the original forest that were not fully cleared for cultivation. These habitats retain native tree species characteristic of the original ecosystem, although their structure and ecological conditions are influenced by surrounding agricultural activities. As a result, they may exhibit unique ecological dynamics shaped by their proximity to agricultural practices, which can influence soil quality, moisture levels and species interactions (Yahya et al. 2023).

Although recent dam projects in Malaysia have emphasised sustainability in monitoring and managing wildlife, limited research has been conducted on the impact on wildlife during the development phase. Detailed studies of bird communities within areas designated for hydroelectric dam construction, are particularly lacking. Habitats have been significantly altered in recently disturbed forests within dam development zones, leading to changes in biodiversity patterns. Understanding these impacts is essential to developing strategies for conservation and sustainable management within dam-affected ecosystems.

Several previous studies have been conducted by our team in a dam development zone in Hulu Terengganu (Adyla et al. 2016; Mohd-Taib et al. 2018; Nasruddin-Roshidi et al. 2021; Ismail et al. 2022). However, no assessment has been carried out on how recently disturbed landscapes affect bird diversity during the pre-construction phase. Therefore, this study aimed to evaluate avian species diversity across habitats situated along a dam construction gradient, including recently disturbed forests, agricultural-forest patches and mosaic habitats, all of which have been fragmented by logging roads and land clearing. Specifically, we sought to: (1) compare species richness and abundance across habitat types; (2) assess variation in species composition amongst the three habitats and (3) identify species of conservation concern, particularly those vulnerable to disturbance. We hypothesised that larger and less disturbed forest patches would support greater diversity and abundance of forest-dependent and specialist species, whereas more modified habitats, such as mosaics or agroforestry zones, would support a higher proportion of generalist and edge-adapted species. We also expected that species of conservation concern to show greater sensitivity to habitat disturbance due to their ecological specialisations. Although some species may persist during the logging phase, we anticipated that ongoing habitat alteration would reduce overall diversity and abundance (Irving et al. 2018; Nasruddin-Roshidi et al. 2021; Ismail et al. 2022). Studying bird diversity during the active development phase is, therefore, critical for understanding community-level responses and providing baseline data to guide conservation planning near hydroelectric dam sites.

Study area

This study was conducted in the Nenggiri hydroelectric dam catchment area, located in Mukim Ulu Nenggiri, Gua Musang District, Kelantan, located in the central-eastern Peninsular Malaysia, within the southern part of Kelantan. This region is characterised by tropical rainforest, which supports a high diversity of plant and animal species. The catchment area features a heterogeneous landscape comprising various habitat types, ranging from pristine and recently disturbed forests to agricultural-forestry patches, mosaic habitats, orchards, oil palm plantations, rubber plantations, human settlements, work areas and barren land (Fig. 1). Six study sites comprising different habitats were selected to assess the pattern of avian species diversity along the dam construction gradient. The habitats were Recently Disturbed Forests (RD), Agricultural–Forest Patches (AFP) and Mosaic Habitats (MH). The RD represented a natural forest that had been fragmented due to dam-related development activity. These sites are adjacent to barren land where deforestation and logging began approximately in mid-2022. This fragmentation has reduced the overall forest size, increased the distances between

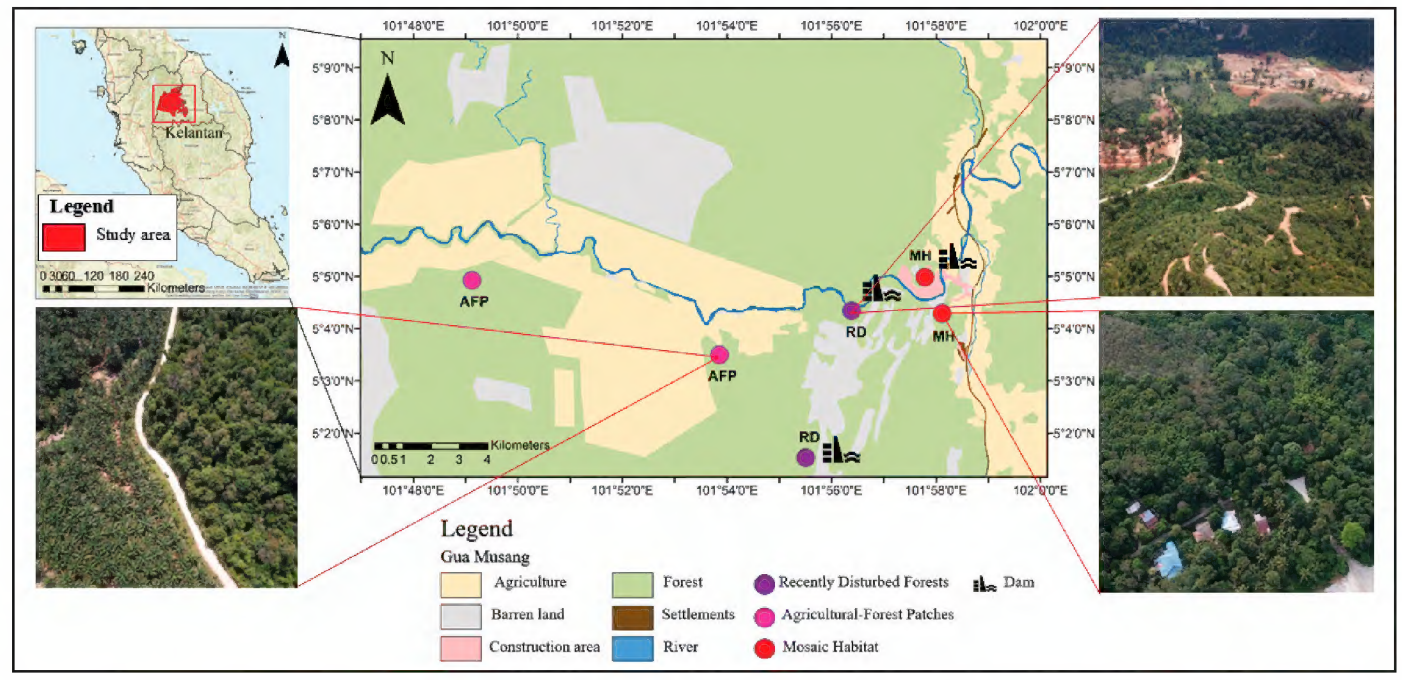

Figure 1. Locations of the study sites in the Nenggiri Hydroelectric Dam area, Gua Musang, Kelantan. The inset map shows an aerial view of Recently Disturbed Forests (RD), Agricultural–Forest Patches (AFP) and Mosaic Habitat (MH).

patches and altered the surrounding landscape. Fragmentation results in edge effects, where the conditions of the forest edges become significantly different from the interior. The AFP represented a transition zone between natural forest ecosystems and adjacent agricultural areas, particularly oil palm plantations (*Elaeis guineensis*). This patch was uniquely positioned as a buffer zone, blending the characteristics of both forest and agricultural landscapes. The MH comprised a mixture of natural forest, agricultural crops such as rubber (*Hevea brasiliensis*) and orchards containing fruit-bearing trees, such as durian (*Durio zibethinus*) and cocoa (*Theobroma cacao*). Site selection was guided by dominant tree composition, drone imagery for large-scale assessment, land-use maps and digitised 2024 Landsat imagery. All sampling sites were located within a 5 km radius of anthropogenic disturbance areas, including logging zones and construction sites.

Field survey methods

Two field survey methods were used: point counts and mist-netting. The data were collected from July 2022 until July 2024 during the early stages of dam development, encompassing both the dry season (May to September) and the wet season (October to April), typical of Malaysia's tropical rainforest climate. For point counts, we recorded all birds detected visually or aurally. This method is suitable for habitats with dense vegetation and high canopy cover. Each habitat type was represented by two study sites and, at each site, five point-count stations were established, spaced by 200 m apart. Counts were conducted for 20 minutes between 0700–1000 h and 1600–1900 h, corresponding to peak activity periods. Each site was visited three times per sampling period, yielding a total sampling effort of 30 hours (MacKenzie et al. 2017). Surveys were avoided during adverse weather, such as rain and strong winds. Observations were made using binoculars (Minox BV 10x42) and species identifications followed Robson (2014). For mist-netting, ten nets (2.5 m × 9 m × 4 m; mesh size 36 mm) were set up at each study site from 0700 to 1900 h over five consecutive days per field session. Nets were monitored every two hours and captured birds were fitted with numbered aluminium rings on the tarsus to avoid double counting, photographed and released unharmed. The total mist-netting effort across all sessions amounted to 3,600 net-hours.

Data analysis

We implemented species rarefaction and extrapolation techniques for evaluating bird diversity by utilising Hill numbers, a collection of metrics that quantify several dimensions of diversity, distinguished by an order parameter q. At q = 0, the Hill number represents species richness, effectively counting the number of distinct species present. At q = 1, the Hill number assesses both species richness and evenness, examining not only the quantity of species present, but also the uniformity of their individual abundances. At q = 2, the Hill number corresponds to the Simpson diversity index, which quantifies variety by squaring the fraction of each species relative to the total number of individuals, thereby emphasising dominating species. As q expands, the impact of rarer species in the calculation diminishes (Jost 2006; Chao et al. 2014), hence assigning greater significance to abundant species. As q approaches infinity, the metric converges to the abundance of the predominant species (Hill 1973). The Chao 1 index yields an estimate of species richness if sampling is prolonged. We examined the diversity indices to assess the total number of bird species occurring across these habitats using the iNEXT online website (Chao et al. 2014) and the Chao 1 index analysis using PAST Software (Paleontological Statistics, Version 4.03, Hammer and Harper (2001)).

The Shapiro-Wilks test for normality showed the data were not normally distributed. The differences in bird species abundance amongst the three habitats were analysed using Pearson's Chi-squared test, followed by post-hoc analyses to identify significant pairwise differences. Variation in bird species composition was assessed at each observation point using non-metric multidimensional scaling (NMDS) with the Bray–Curtis index in PAST software. Bar plots and box plot diagrams were used to illustrate total species richness and abundance for the three habitats along the dam construction gradient and bar plots were used to show the proportions of species by feeding guilds across the three habitat types. All plots were generated using the ggplot2 package for R Software (R Development Core Team 2020; Oksanen et al. 2023). Bird species were classified into forest-dependent, non-forest dependent and feeding guilds, based on trophic groups as suggested by Robson (2014), Nasruddin-Roshidi et al. (2021) and Razali et al. (2022).

Results

A total of 727 bird observations representing 120 species and 40 families were recorded across the study area. The AFP showed the highest diversity of bird species, followed by RD and MH (Fig. 2). The family Pycnonotidae had the highest number of recognised species (12 species) across the three habitats, followed by Muscicapidae (12 species), Cuculidae (eight species) and Cisticolidae (six species). Black-headed Bulbul (*Microtarsus melanocephalos*), Yellow-bellied Bulbul (*Alophoixus phaeocephalus*), Yellow-vented Bulbul (*Pycnonotus goiavier*), Red-eyed Bulbul (*Pycnonotus brunneus*) and Spectacled Bulbul (*Rubigula erythropthalmos*) were relatively common in the study area. The most abundant species recorded from mist-netting were Little Spiderhunter (*Arachnothera longirostra*), Asian Emerald Dove (*Chalcophaps indica*) and Yellow-bellied Bulbul (*Alophoixus phaeocephalus*).

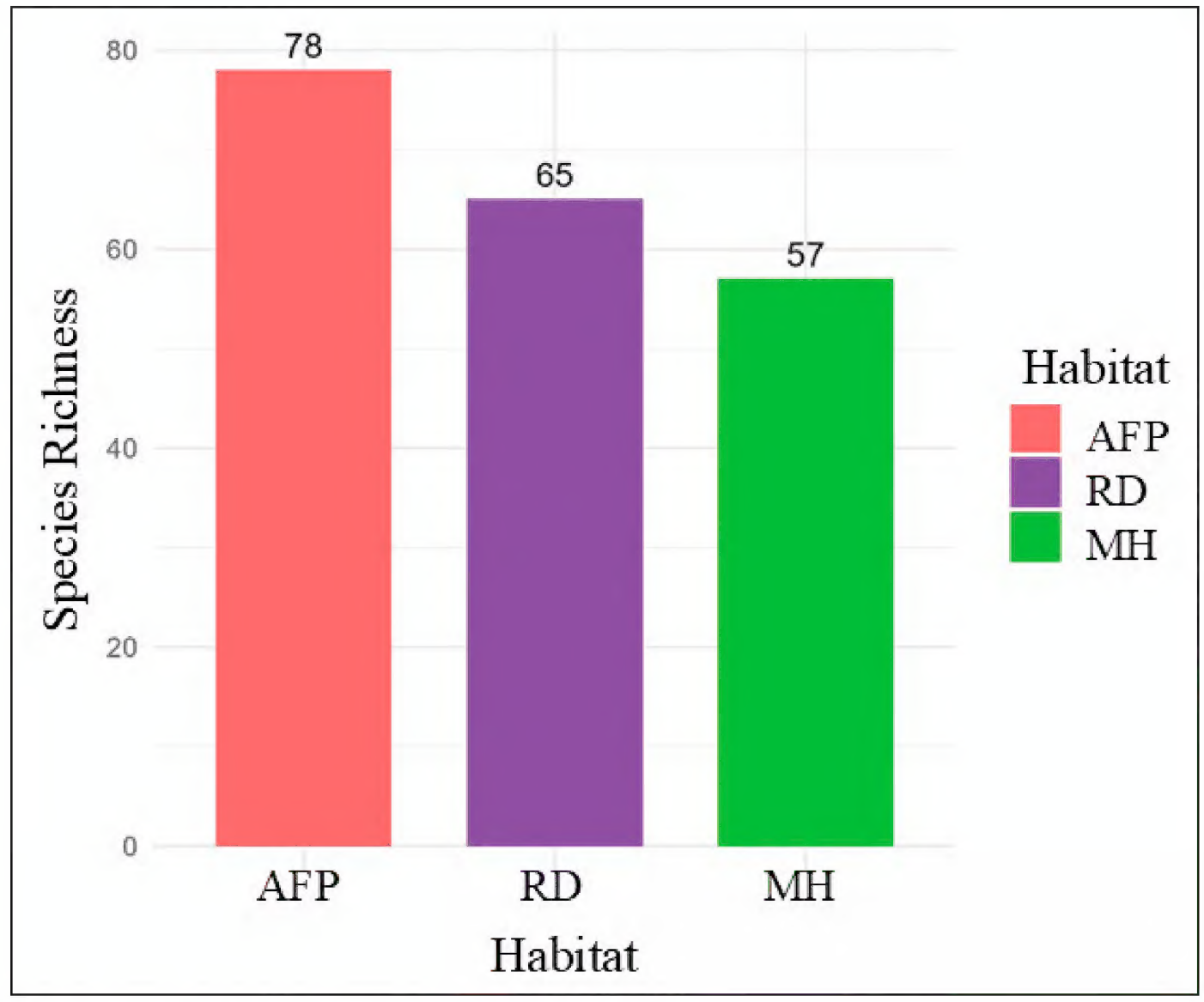

Figure 2. Species richness for three habitat types.

According to habitat, a total of 78 species (39% of total species and the highest amongst all habitats) and 210 individuals (29% of total individuals) occurred in AFP, followed by 65 species (33%) and 279 individuals (38% of the total individuals and the highest amongst all habitats) in RD. The least species-rich was MH, with only 57 species (29%) and only 238 individuals (33%) being recorded (Fig. 2, Table 1). The Chao 1 richness estimator indicates that the estimated species richness was highest in AFP at 144 species, followed by RD at 132 species and lowest in MH at 84 species (Table 1). The boxplot (Fig. 3) illustrates the abundances of the species throughout the three study habitats. AFP and MH had higher median bird abundance compared to RD, although RD exhibited the most variability. The abundance of the habitat-specific avifauna is included as a supplementary file (Suppl. material 1).

The study identified a total of 90 forest-dependent species and 30 non-forest-dependent species, indicating a strong reliance on forest habitats amongst the avian community surveyed. Amongst the habitat types, AFP supported the highest number of forest-dependent species (n = 62), whereas RD and MH each harboured 42 forest-dependent species, highlighting the variation in species distribution across different forest conditions. Overall, forest-dependent birds accounted for 75% of the total species richness, emphasising the critical role of

Table 1. Bird diversity indices from all sampling sites across three habitats.

Habitat	Abundance	Species	Chao 1 richness estimator	Coverage estimates	Coverage estimates for twice	Estimated diversity at 95% coverage		
						q = 0	q = 1	q = 2
AFP	210	78	144	0.801	0.888	109.92	58.32	31.05
RD	279	65	132	0.868	0.919	76.43	25.15	10.51
MH	238	57	84	0.891	0.953	56	22.23	8.9

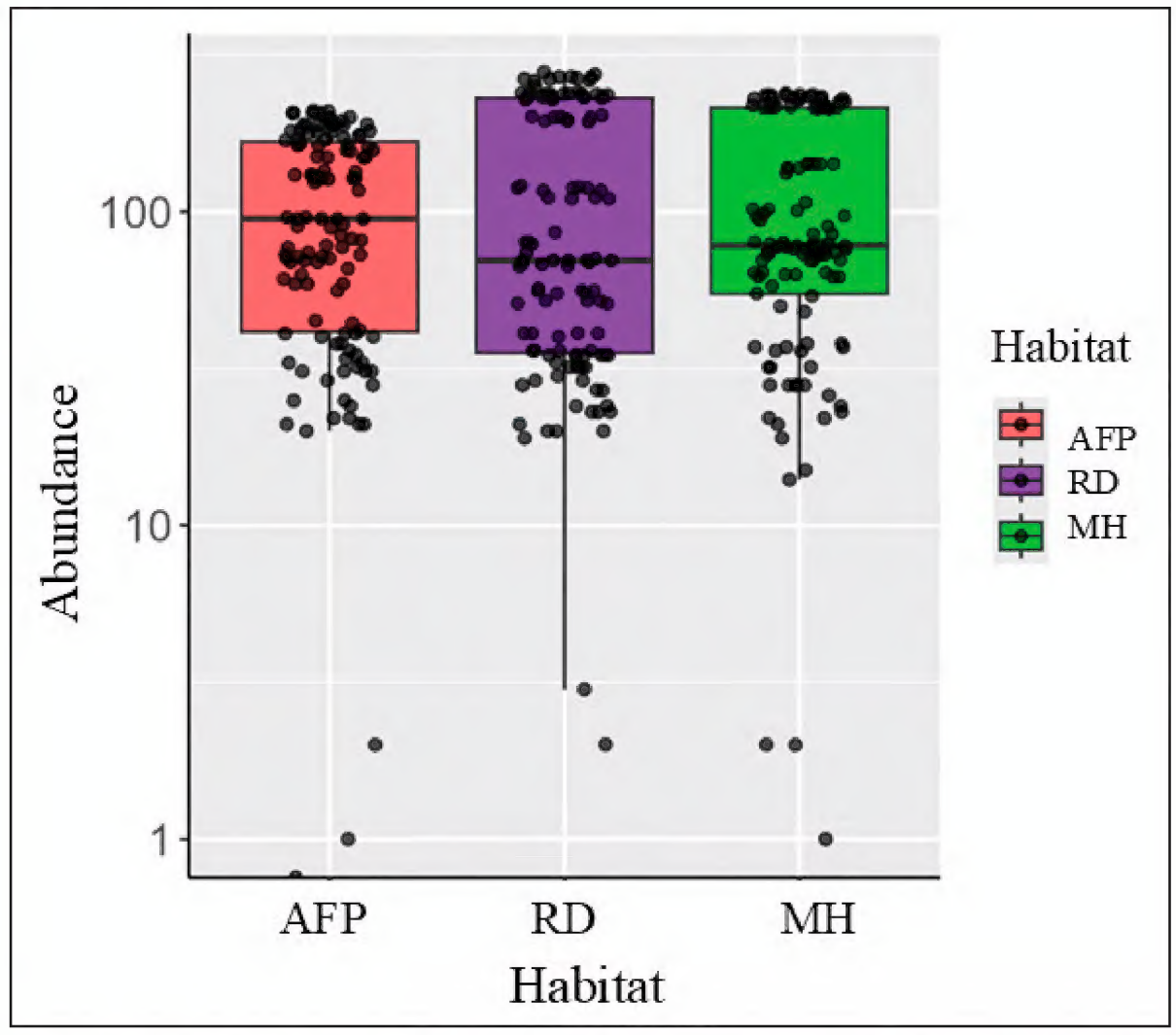

Figure 3. Boxplots illustrating the observed abundance of birds across three habitat types. Each point represents an individual observation at a point count station. Boxes represent the interquartile range (IQR), showing the middle 50% of the data. The horizontal line within each box indicates the median. Whiskers extend to the minimum and maximum values within 1.5 times the IQR. Points beyond the whiskers represent outliers.

forest ecosystems in sustaining avian biodiversity. A comprehensive list of forest-dependent and non-forest-dependent species is provided in Suppl. material 1. Amongst the recorded species, one, the Greater Green Leafbird (*Chloropsis sonnerati*), was categorised as an Endangered (EN) species in the IUCN Red List. Five species were categorised as Vulnerable (VU): Brown-chested Jungle Flycatcher (*Cyornis brunneatus*), Grey-cheeked Bulbul (*Alophoixus tephrogenys*), Javan Myna (*Acridotheres javanicus*), Rhinoceros Hornbill (*Buceros rhinoceros*) and Wreathed Hornbill (*Rhyticeros undulatus*). Another 18 species were categorised as Near Threatened (NT), while the remaining species were in the least concern (LC) category (IUCN 2025) (Suppl. material 1).

The bird species diversity differed significantly amongst the three habitats sampled (Pearson's Chi-squared test: X^2 = 606.01, df = 238, $p \leq 0.05$). Pairwise Bonferroni analysis showed that the bird species diversity of AFP was significantly different from that of MH ($p \leq 0.05$). AFP exhibited the highest species richness (78 species; Chao 1 index = 144) and diversity estimates across all scales (q = 0: 109.92; q = 1: 58.32; q = 2: 31.05), despite lower sampling coverage (q = 0: 0.801). RD had the highest abundance (279 individuals), but fewer species (65; Chao 1 index = 132), with diversity estimates (q = 0: 76.43; q = 1: 25.15; q = 2: 10.51) indicating a community increasingly dominated by fewer species. MH showed the lowest species richness (57; Chao 1 index = 84) and diversity (q = 0: 56; q = 1: 22.23; q = 2: 8.9), with the highest sampling coverage (q = 0: 0.891).

The coverage-based rarefaction curves for the three study habitats showed steady increases, indicating that more species are expected to be discovered in these areas (Fig. 4). Diversity estimates for orders q = 0 (Species richness), q = 1

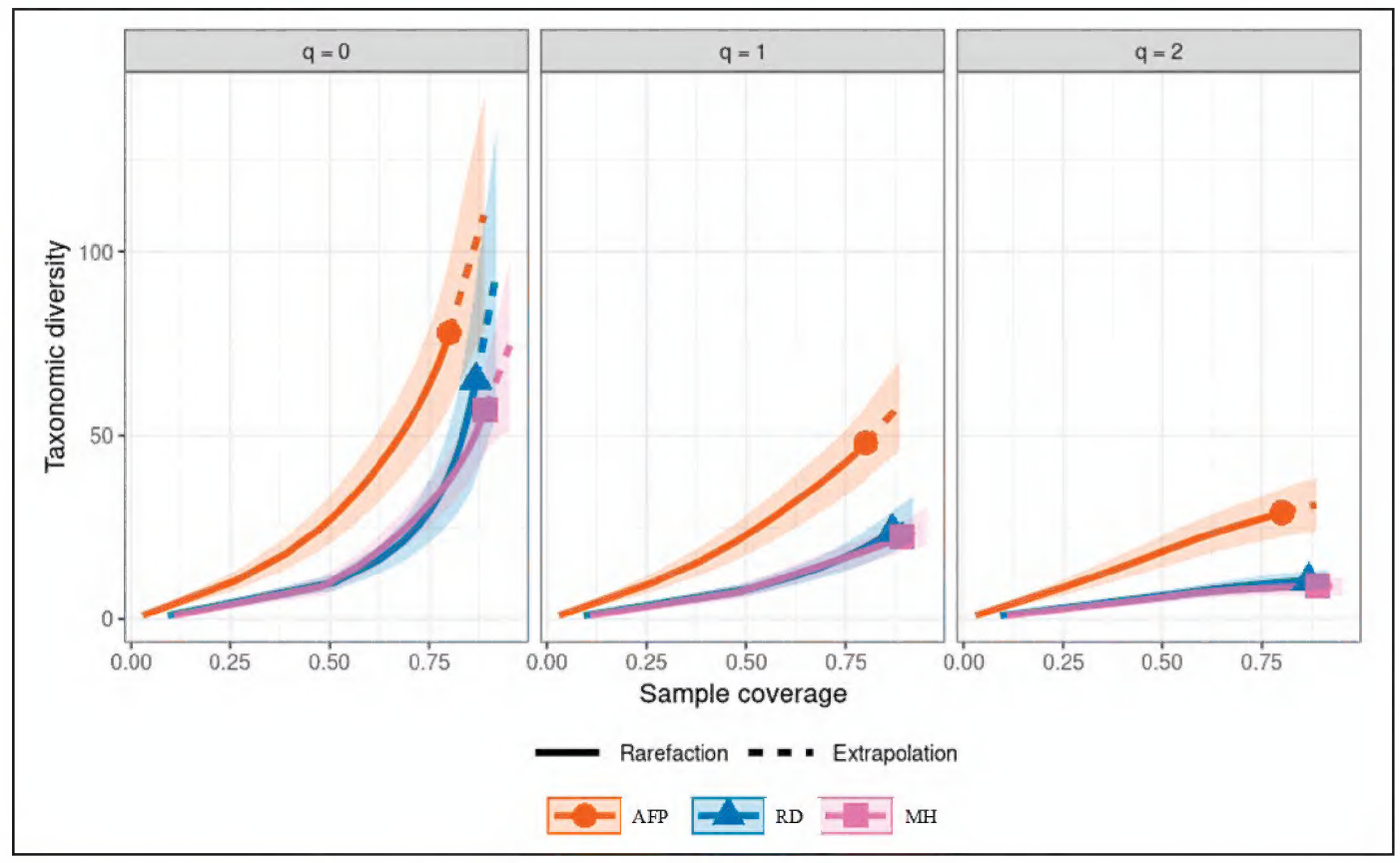

Figure 4. Coverage-based rarefaction and extrapolation generated using iNEXT function for bird communities across the three habitat types.

(Shannon diversity) and q = 2 (Simpson diversity), each plotted with 95% confidence intervals, indicated that AFP had the highest estimated diversity, while MH had the lowest. Interpolation at the site with the lowest species abundance (AFP) of 210 individuals showed that AFP had the highest number of species (78), followed by RD (55.22) and MH (53.79). The iNEXT analysis showed that the estimated coverage values for the reference samples were 0.801 for AFP, 0.868 for RD and 0.891 for MH (Fig. 4). Higher sample coverage numbers that approach 1.0 indicate that the sampling effort has successfully captured the majority of species, whereas lower values signal that numerous species remain unrepresented.

Non-metric Multidimensional Scaling (NMDS) analysis showed that the composition of bird species varied significantly amongst the observation points (stress = 0.3875, R^2 values for axis 1 = 0.7152 and for axis 2 = 0.0561) (Fig. 5). The NMDS plot visually presents the differences in species composition amongst the three habitats. The data were collected over two study sites for each habitat and each site has 5-point counts, providing a temporal

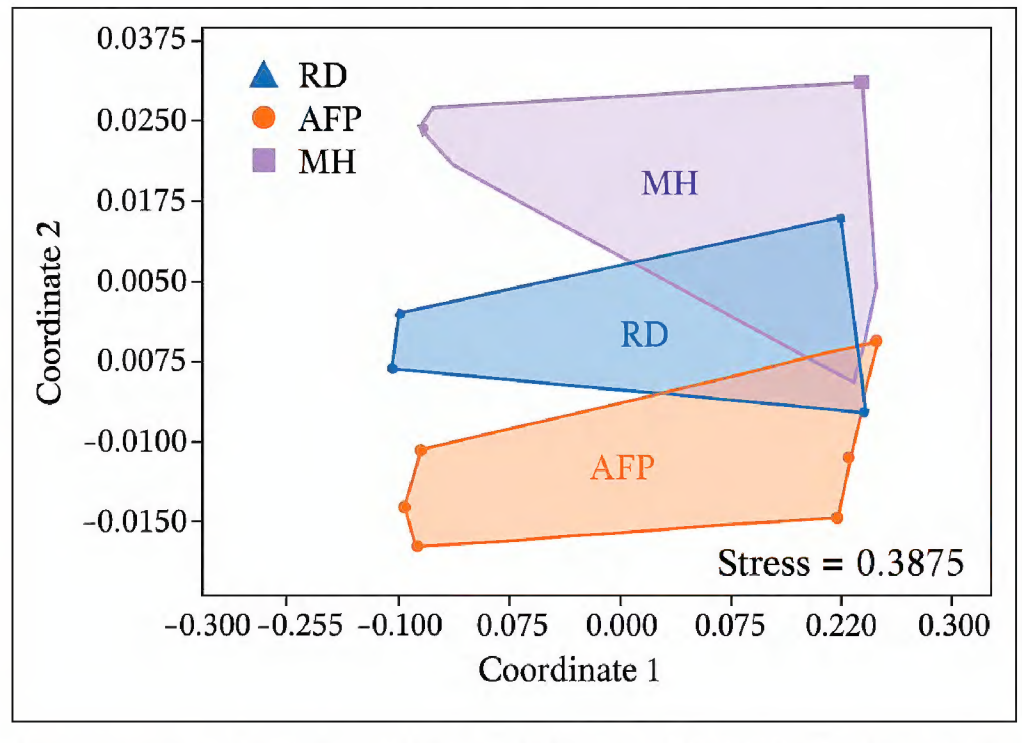

Figure 5. Non-parametric Multidimensional Scaling (NMDS) showing the difference in species composition across three habitats.

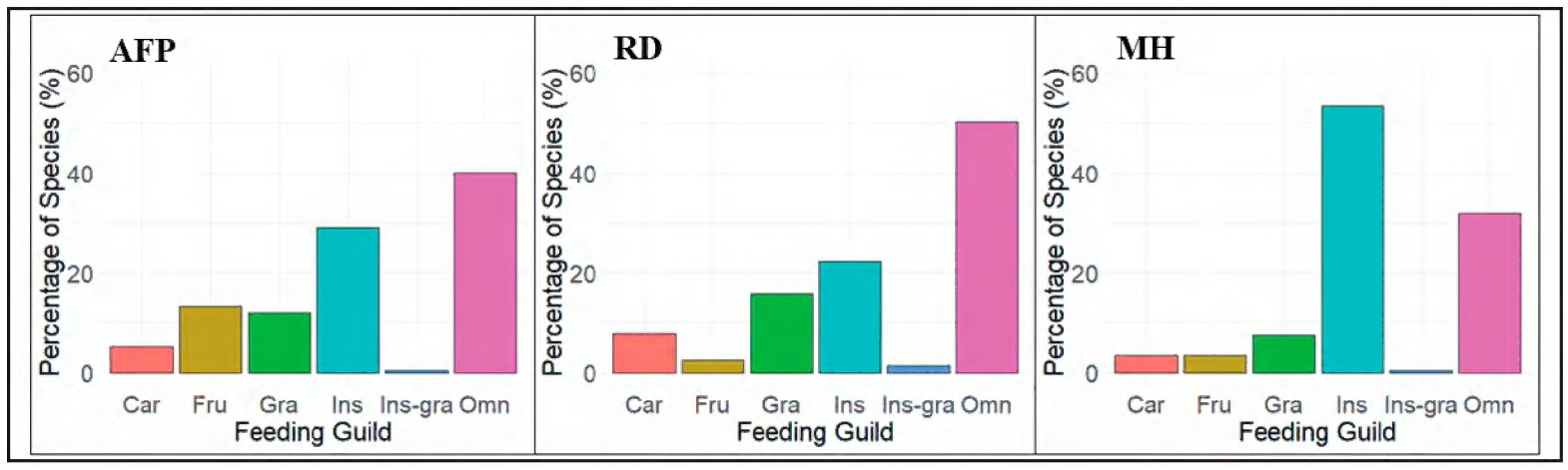

Figure 6. Proportions of species by feeding guilds across three habitat types. Feeding Guild: Ins = insectivores, Fru = frugivores, Omn = omnivores, Car = carnivores, Gra = granivores.

dimension to the analysis. AFP appeared more distinct from RD and MH, while the latter two appear more similar to each other, based on the relative distances in the plot (Fig. 5).

The proportions of bird species in different feeding guilds across the three habitats showed that omnivorous birds dominated both AFP and RD, contributing the largest proportion of the community at over 40%. In contrast, insectivorous birds were the most prevalent in MH, comprising more than 50% of the community (Fig. 6).

Discussion

The results revealed that agricultural-forest patch habitats supported greater bird diversity than recently disturbed forests and mosaic habitats. These habitats encompassed a range of feeding guilds and forest-dependent species, including six species listed as threatened on the IUCN Red List. The higher diversity observed in agricultural-forest patches likely reflects their greater structural complexity and the wider availability of ecological niches, consistent with findings by Gregory and Strien (2010), who reported higher avian diversity in structurally complex environments. These findings highlight the ecological importance of remnant forests and habitat rehabilitation in maintaining biodiversity within large-scale development landscapes (Tuen et al. 2018; Nasruddin-Roshidi et al. 2021; Ismail et al. 2022). Remnant forest patches within modified tropical landscapes provide essential refuges for threatened bird species (Mansor et al. 2018; Martínez-Ruiz et al. 2024).

Agricultural-forest patches are still able to support high species richness because the nearby forest patches are large in size and connected to other forest areas. Forest areas with diverse microhabitats and foraging niches provide abundant food resources and can sustain larger bird populations (Mansor et al. 2018; Hendershot et al. 2023). Sensitive bird species require extensive areas to meet their foraging and ranging needs (Mansor et al. 2018). The connectivity of forest patches plays an important role in maintaining bird population persistence within landscapes fragmented by agriculture and dam construction (Kang et al. 2015; Nasruddin-Roshidi et al. 2021). Connected or closely-situated forest patches allow birds to move between habitats and reduce the risk of population isolation (Mohd-Taib et al. 2014). Conversely, forest patches that are widely separated create severe fragmentation, trapping birds within small areas with limited resources, which ultimately reduces breeding success and increases the risk of local extinction (Coddington et al. 2023).

The recently disturbed forests recorded the second-highest species diversity due to their degraded secondary forest quality and being surrounded by logging-impacted areas that potentially impose ecological pressure on bird communities (Aida et al. 2016). The area is dominated by generalist and opportunistic bird species that tend to thrive in degraded and fragmented environments, such as the Red Junglefowl (*Gallus gallus*), the Asian Emerald Dove (*Chalcophaps indica*) and the Crested Serpent-Eagle (*Spilornis cheela*). Bird species within this habitat were unevenly distributed, a pattern that may be due to anthropogenic pressure on the landscape and forest edge effects (Ma et al. 2023). The clearing of land and logging activities increase exposure to predators and invasive species and may lead to changes in the microclimate that can adversely affect the species living in these areas (Lee et al. 2024; Rahim et al. 2025). Despite their small size and proximity to logging-disturbed areas, these forest patches are still capable of supporting a considerable number of bird species. Nevertheless, such habitats are likely to function as ecological sinks, representing suboptimal environments that cannot sustain viable populations without demographic or dispersal support from larger, higher-quality forest blocks (Yang et al. 2024). The existence of sink habitats remains important, as they provide temporary refuges and movement corridors for birds affected by surrounding disturbances (Eberhart-Hertel and Colwell 2014).

The mosaic habitats had less bird diversity compared to the other two habitats, potentially due to suboptimal habitat conditions. This site was exposed to the environment and anthropogenic influences, with the potential to affect bird diversity and affect how different bird species use this habitat (Wegner and Wolter 2024). Interference by humans is the main reason for the reduction in species diversity (Fontúrbel et al. 2021; Rajagopal et al. 2022; Aksan 2023). Invasive species, such as the Javan Myna (*Acridotheres javanicus*) and Common Myna (*Acridotheres tristis*), have also been recorded within the study area; these birds are well-known opportunistic omnivores due to their capacity to adapt to and exploit human food waste (Yap and Sodhi 2004; Arazmi et al. 2022; Khiruddin et al. 2025). In some cases, human settlements may mitigate disturbance to adjacent forest areas by preserving the available natural spaces and restricting their activities to specific uses, such as small-scale agriculture and orchards (Davis et al. 2024). This can contribute to the preservation of forest habitats, in turn supporting the species that depend on them. The presence of heterogeneous habitats, such as forests interspersed with orchards, agricultural land and human settlements, creates a variety of ecological niches and changes in farming practices by the local community may influence avian diversity (Brambilla et al. 2015; Šálek et al. 2021). The mosaic habitat that exists due to the interactions amongst forests, orchards and human settlements can create a dynamic environment that fosters a high species diversity, particularly when the area is managed sustainably.

Six feeding guilds were present in this study and the most dominant feeding guilds across each habitat were the omnivores and insectivores. The dominance of omnivorous birds in agricultural-forest patches and recently disturbed forests reflects how these habitats support generalist species capable of utilising a wide range of food resources. The composition of omnivores included species such as the Red Junglefowl (*Gallus gallus*) and the Jungle Myna (*Acridotheres fuscus*). These species are notable for their dietary flexibility, as they feed on a diverse range of food sources, including seeds, fruits, insects and

human-provided food (Santamaria-Rivero et al. 2016). The high presence of insectivorous birds in mosaic habitats may reflect the characteristics of suboptimal or sink habitats that temporarily support populations, while their long-term persistence likely depends on connectivity with surrounding forests (Catfolis et al. 2023). Forest-dependent species exhibited substantially higher abundance in AFP, accounting for approximately 75%, compared to only 25% in RD and MH. Key forest-dependent species, such as the Rhinoceros Hornbill (*Buceros rhinoceros*), Bushy-crested Hornbill (*Anorrhinus galeritus*) and Greater Green Leafbird (*Chloropsis sonnerati*), were predominantly associated with these forested areas (Buchanan et al. 2011; Jones et al. 2021). These species are highly sensitive to habitat fragmentation and degradation and, thus, serve as reliable indicators of primary forest integrity (Anggraini et al. 2000; Nordin et al. 2025). This pattern highlights the ecological importance of maintaining diverse habitat types and highlights the critical role of remnant forests in sustaining stable avian communities and supporting broader ecosystem integrity.

The present study provides insights into the local ecological conditions and the potential habitat preferences of bird species inside the development area of the Nenggiri Hydroelectric Project. Overall, the remaining forest within the development zones, such as AFP, RD and MH, potentially serves as refugia for many bird species. These areas provide essential shelter and resources, making it vital to avoid large-scale clearing. Some bird species may be sensitive to habitat modification and they may appear to be occupying the areas with less disturbance by choosing the forest patches. According to our observations, the periphery of forest patches along the dam construction gradient is dominated by a mixture of native tree species and potentially provides a more suitable habitat for many of the bird species, as they are being used as a refuge habitat during the development of the hydroelectric dam. Tree composition and forest structure strongly affect bird species composition and, thus, ecological functions (Jung et al. 2024). Vegetation density, vegetation structure, physical variables affecting vegetation structure and habitat complexity have been demonstrated to be the most significant variables impacting bird species richness and abundance (Mansor et al. 2020b; Mansor et al. 2022; Aksan 2023).

The findings of this study revealed agricultural-forest patches exhibited greater species richness, supporting higher species compared to species in recently disturbed forests and mosaic habitats. This disparity may be attributed to the more complex structure and availability of diverse food resources in agricultural patches. Estimated diversity at 95% coverage (q = 0, 1, 2) was higher in agricultural-forest patches, indicating a balanced distribution of bird populations, whereas recently disturbed forests and mosaics demonstrated dominance by a few species, suggesting potential habitat degradation. However, recently disturbed forests and mosaic habitats still supported a large number of bird species within these habitats. The Chao 1 richness estimator and coverage estimates in this study indicate a higher value, suggesting that our sampling effort was sufficient to capture a representative portion of the bird species present in the area. The Chao 1 estimator, which accounts for undetected species based on observed data, reflects an estimated species richness that exceeds our direct observations. The coverage estimates indicate that a substantial proportion of the expected species were included in our survey, reinforcing the reliability of our findings and the robustness of the methodologies employed (Chao et al. 2014).

The species identified as threatened in the IUCN Red List within this study are also highly prevalent, making this a critical indicator for the preservation of the area. The study identified six threatened bird species listed in the IUCN Red List as Endangered (EN) and Vulnerable (VU) within the surveyed area. While this study provides valuable insights into bird diversity across AFP, RD and MH, several limitations should be acknowledged. The study included only two sites per habitat type, limiting spatial replication and reducing the generalisability of the findings. This limitation was largely due to accessibility constraints, particularly during the logging and construction phases, when site selection was restricted to the remaining accessible habitats. Addressing these limitations in future studies through increased site replication and broader spatial coverage will enhance the reliability and applicability of biodiversity assessments in human-modified landscapes.

Planning conservation and rescue efforts before initiating developmental activities near the hydroelectric dam area is critical and priority should be based on species richness and endangered species. This would avoid the negative effects of logging or the development of a dam, such as mainland edge effects and the associated human disturbance of the habitat (Irving et al. 2018). This study emphasises the importance of integrating biodiversity conservation into sustainable development strategies, particularly in landscapes affected by human activities. Maintaining the remaining natural habitats within the catchment and surrounding areas of these landscapes is crucial for preserving bird diversity and the ecosystem functions they support. Sustainable plantation management should include the retention and restoration of forest patches and natural habitats to ensure that these landscapes can continue to support bird populations. To effectively target conservation goals, it is essential to engage with all relevant stakeholders and local communities. Conservation efforts should focus on enhancing habitat quality and connectivity to mitigate the effects of fragmentation, while promoting land-use practices that balance production and biodiversity conservation.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

Field studies were conducted in accordance with and in collaboration with, the Department of Wildlife and National Parks Peninsular Malaysia (PERHILITAN) and were carried out under the guidelines of the Wildlife Conservation Act 2010 (Act 716).

Use of AI

No use of AI was reported.

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Author contributions

Mohammad Saiful Mansor: Writing – original draft, Visualisation, Writing – review and editing, Validation, Supervision, Methodology, Investigation, Conceptualisation. Norfazliyana Nordin: Methodology, Investigation, Formal analysis. Fudzla Zulfa Khiruddin: Methodology. Nor Adibah Ismail: Methodology. Ummi Nur Syafiqah Daud: Data curation, Investigation. Nurfatin Batrisyia Md Ali: Data curation, Investigation. Saiful Hilmi Jamal Shuhaily: Data curation, Investigation. Ahmad Khusaini Mohd Kharip Shah: Project administration, Supervision. Aisah Shukor: Funding acquisition, Project administration, Resources. Shukor Md Nor: Funding acquisition, Project administration. All authors contributed equally to the final version of the manuscript.

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Data availability

Data will be made available on request.

References

Adyla MNN, Ikhwan Z, Zuhairi MN, Nor SM (2016) Diversity and activity pattern of wildlife inhabiting catchment of Hulu Terengganu Hydroelectric Dam, Terengganu, Peninsular Malaysia. AIP Conference Proceedings 1784(1): 060038. https://doi.org/10.1063/1.4966876

Aida N, Sasidhran S, Kamarudin N, Aziz N, Puan CL, Azhar B (2016) Woody trees, green space and park size improve avian biodiversity in urban landscapes of Peninsular Malaysia. Ecological Indicators 69: 176–183. https://doi.org/10.1016/j.ecolind.2016.04.025

Aksan Ş (2023) Relationships between avian diversity and agricultural landscape heterogeneity. Revista Arvore 47: e4705. https://doi.org/10.1590/1806-908820230000005

Andriolo A, Piovezan U, Da Costa MJRP, Torres HA, Vogliotti A, Zerbini AN, Duarte JMB (2013) Severe population decline of marsh deer, blastocerus dichotomus (Cetartiodactyla: Cervidae), a threatened species, caused by flooding related to a hydroelectric power plant. Zoologia 30: 630–638. https://doi.org/10.1590/s1984-46702013005000015

Anggraini K, Kinnaird M, O'Brien T (2000) The effects of fruit availability and habitat disturbance on an assemblage of Sumatran hornbills. Bird Conservation International 10: 189–202. https://doi.org/10.1017/S0959270900000174

Arazmi FN, Ismail NA, Daud UNS, Abidin KZ, Nor SM, Mansor MS (2022) Spread of the invasive Javan myna along an urban–suburban gradient in Peninsular Malaysia. Urban Ecosystems 25: 1007–1014. https://doi.org/10.1007/s11252-022-01216-9

Brambilla M, Assandri G, Martino G, Bogliani G, Pedrini P (2015) The importance of residual habitats and crop management for the conservation of birds breeding in intensive orchards. Ecological Research 30: 597–604. https://doi.org/10.1007/s11284-015-1260-8

Brose U, Blanchard JL, Eklöf A, Galiana N, Hartvig MR, Hirt M, Kalinkat G, Nordström MC, O'Gorman EJ, Rall BC (2017) Predicting the consequences of species loss using size-structured biodiversity approaches. Biological Reviews of the Cambridge Philosophical Society 92: 684–697. https://doi.org/10.1111/brv.12250

Brown CJM, Noble BF, Munkittrick KR (2024) Examination of recent hydroelectric dam projects in Canada for alignment of baseline studies, predictive modeling, and post-development monitoring phases of aquatic environmental impact assessments. Integrated Environmental Assessment and Management 20: 616–644. https://doi.org/10.1002/ieam.4823

Buchanan GM, Donald PF, Butchart SHM (2011) Identifying Priority Areas for Conservation: A Global Assessment for Forest-Dependent Birds. PLoS ONE 6: e29080. https://doi.org/10.1371/journal.pone.0029080

Catfolis B, Vanroy T, Verheyen K, Baeten L, Martel A, Pasmans F, Strubbe D, Lens L (2023) Avian nutritional condition increases with forest structural complexity. Ecological Indicators 154: 110536. https://doi.org/10.1016/j.ecolind.2023.110536

Chao A, Gotelli NJ, Hsieh TC, Sander EL, Ma KH, Colwell RK, Ellison AM (2014) Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies. Ecological Monographs 84: 45–67. https://doi.org/10.1890/13-0133.1

Coddington C, Cooper W, Luther D (2023) Effects of forest fragmentation on avian breeding activity. Conservation Biology 37. https://doi.org/10.1111/cobi.14063

Davis S, Guerreiro Milheiras S, Olivier PL, Barnes L, Shirima D, Kioko E, Sallu SM, Ishengoma E, Marshall AR, Pfeifer M (2024) Cropland can support high bird diversity in heterogeneous rural tropical landscapes. Bird Conservation International 34: e13. https://doi.org/10.1017/S0959270924000030

Eberhart-Hertel L, Colwell M (2014) Conservation challenges of a sink: The viability of an isolated population of the Snowy Plover. Bird Conservation International 24: 327–341. https://doi.org/10.1017/S0959270913000506

Eglington SM, Noble DG, Fuller RJ (2012) A meta-analysis of spatial relationships in species richness across taxa: Birds as indicators of wider biodiversity in temperate regions. Journal for Nature Conservation 20: 301–309. https://doi.org/10.1016/j.jnc.2012.07.002

Egwumah FA, Egwumah PO, Edet DI (2017) Paramount roles of wild birds as bioindicators of contamination. International Journal of Avian & Wildlife Biology 2: 00041. https://doi.org/10.15406/ijawb.2017.02.00041

Fimbel RA, Grajal A, Robinson JG (2001) Logging and wildlife in the tropics: impacts and options for conservation. The cutting edge: Conserving wildlife in logged tropical forests. Columbia University Press, 667–696. https://doi.org/10.7312/fimb11454-037

Fontúrbel FE, Orellana JI, Rodríguez-Gómez GB, Tabilo CA, Castaño-Villa GJ (2021) Habitat disturbance can alter forest understory bird activity patterns: A regional-scale assessment with camera-traps. Forest Ecology and Management 479: 118618. https://doi.org/10.1016/j.foreco.2020.118618

Gardali T, Marty J, Yarris G (2017) The Science of Setting Conservation Objectives for Birds in California's Central Valley: An Introduction. San Francisco Estuary and Watershed Science 15(1): 1. https://doi.org/10.15447/sfews.2017v15iss1art1

Grande JM, Orozco-Valor PM, Liébana MS, Sarasola JH (2018) Birds of Prey in Agricultural Landscapes: The Role of Agriculture Expansion and Intensification. In: Sarasola J, Grande J, Negro J (Eds) Birds of Prey. Springer, Cham, 197–228. https://doi.org/10.1007/978-3-319-73745-4_9

Grantham HS, Duncan A, Evans TD, Jones KR, Beyer HL, Schuster R, Walston J, Ray JC, Robinson JG, Callow M, Clements T, Costa HM, DeGemmis A, Elsen PR, Ervin J, Franco P, Goldman E, Goetz S, Hansen A, Hofsvang E, Jantz P, Jupiter S, Kang A, Langhammer P, Laurance WF, Lieberman S, Linkie M, Malhi Y, Maxwell S, Mendez M, Mittermeier R, Murray NJ, Possingham H, Radachowsky J, Saatchi S, Samper C, Silverman J, Shapiro A, Strassburg B, Stevens T, Stokes E, Taylor R, Tear T, Tizard R, Venter O, Visconti P, Wang S, Watson JEM (2020) Anthropogenic modification of forests means only 40% of remaining forests have high ecosystem integrity. Nature Communications 11: 5978. https://doi.org/10.1038/s41467-020-19493-3

Gregory RD, Strien VA (2010) Wild bird indicators: Using composite population trends of birds as measures of environmental health. Ornithological Science 9(1): 3–22. https://doi.org/10.2326/osj.9.3

Hammer Ø, Harper DA (2001) Past: Paleontological statistics software package for educaton and data anlysis. Palaeontologia Electronica 4: 1.

Hendershot JN, Echeverri A, Frishkoff LO, Zook JR, Fukami T, Daily GC (2023) Diversified farms bolster forest-bird populations despite ongoing declines in tropical forests. Proceedings of the National Academy of Sciences of the United States of America 120: e2303937120. https://doi.org/10.1073/pnas.2303937120

Hill MO (1973) Diversity and evenness: A unifying notation and its consequences. Ecology 54: 427–432. https://doi.org/10.2307/1934352

Hossain M, Huda ASN, Mekhilef S, Seyedmahmoudian M, Horan B, Stojcevski A, Ahmed M (2018) A state-of-the-art review of hydropower in Malaysia as renewable energy: Current status and future prospects. Energy Strategy Reviews 22: 426–437. https://doi.org/10.1016/j.esr.2018.11.001

Irving GJ, Round PD, Savini T, Lynam AJ, Gale GA (2018) Collapse of a tropical forest bird assemblage surrounding a hydroelectric reservoir. Global Ecology and Conservation 16: e00472. https://doi.org/10.1016/j.gecco.2018.e00472

Ismail NA, Daud UNS, Nasruddin-Roshidi A, Arazmi NFN, Shukor A, Nor SM, Mansor MS (2022) Comparing Bird Assemblages in Catchment Areas of Two Hydroelectric Dams in Terengganu, Malaysia. Pertanika Journal of Science & Technology 30: 1479–1490. https://doi.org/10.47836/pjst.30.2.35

IUCN (2025) The IUCN Red List of threatened species. https://www.iucnredlist.org/ [May 16, 2025]

Jaafar WSWM, Said NFS, Maulud KNA, Uning R, Latif MT, Kamarulzaman AMM, Mohan M, Pradhan B, Saad SNM, Broadbent EN, Cardil A, Silva CA, Takriff MS (2020) Carbon emissions from oil palm induced forest and peatland conversion in sabah and Sarawak, Malaysia. Forests 11: 1–22. https://doi.org/10.3390/f11121285

Jones H, Barreto E, Murillo-García O, Robinson S (2021) Turnover-driven loss of forest-dependent species changes avian species richness, functional diversity, and community composition in Andean forest fragments. Global Ecology and Conservation 32: e01922. https://doi.org/10.1016/j.gecco.2021.e01922

Jost L (2006) Entropy and diversity. Oikos 113: 363–375. https://doi.org/10.1111/j.2006.0030-1299.14714.x

Jung K, Teuscher M, Böhm S, Wells K, Ayasse M, Fischer M, Weisser WW, Renner SC, Tschapka M (2024) Supporting bird diversity and ecological function in managed

grassland and forest systems needs an integrative approach. Frontiers in Environmental Science 12: 1401513. https://doi.org/10.3389/fenvs.2024.1401513

Kang W, Minor ES, Park C-R, Lee D (2015) Effects of habitat structure, human disturbance, and habitat connectivity on urban forest bird communities. Urban Ecosystems 18: 857–870. https://doi.org/10.1007/s11252-014-0433-5

Khiruddin FZ, Nordin N, Arazmi FN, Shuhaily SHJ, Effendi MR, Mansor MS (2025) Landscape Parameters and Their Role in Supporting Bird Diversity: A Study of Urban Parks in Greater Kuala Lumpur, Malaysia. Urban Ecosystems 28: 138. https://doi.org/10.1007/s11252-025-01726-2

Kleinschroth F, Healey JR (2017) Impacts of logging roads on tropical forests. Biotropica 49: 620–635. https://doi.org/10.1111/btp.12462

Kour A, Singh D (2023) Documentation of Avian Species Composition and Assemblage in Agricultural Landscapes of Karnal, Haryana. Bulletin of Pure & Applied Sciences-Zoology. https://doi.org/10.48165/bpas.2023.42A.2.6

Lee SXT, Amir Z, Moore JH, Gaynor KM, Luskin MS (2024) Effects of human disturbances on wildlife behaviour and consequences for predator-prey overlap in Southeast Asia. Nature Communications 15: 1521. https://doi.org/10.1038/s41467-024-45905-9

Ma J, Li J, Wu W, Liu J (2023) Global forest fragmentation change from 2000 to 2020. Nature Communications 14: 3752. https://doi.org/10.1038/s41467-023-39221-x

MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey L, Hines JE (2017) Chapter 14 - Species Co-Occurrence. In: MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey LL, Hines JE (Eds) Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier, 509–556. https://doi.org/10.1016/B978-0-12-407197-1.00019-3

Mansor MS, Nor SM, Ramli R, Anuar S (2018) Niche shift in three foraging insectivorous birds in lowland Malaysian forest patches. Behavioural Processes 157: 73–79. https://doi.org/10.1016/j.beproc.2018.09.001

Mansor MS, Nor SM, Ramli R (2020a) Shifts in foraging behaviour of heterospecific flocking birds in a lowland Malaysian rainforest. Behavioural Processes 180: 104229. https://doi.org/10.1016/j.beproc.2020.104229

Mansor MS, Halim MRA, Abdullah NA, Ramli R, Cranbrook EO (2020b) Barn swallows hirundo rustica in peninsular malaysia: Urban winter roost counts after 50 years, and dietary segregation from house-farmed swiftlets aerodramus sp. The Raffles Bulletin of Zoology 68: 238–248. https://doi.org/10.26107/RBZ-2020-0021

Mansor MS, Rozali FZ, Davies S, Nor SM, Ramli R (2022) High-throughput sequencing reveals dietary segregation in Malaysian babblers. Current Zoology 68: 381–389. https://doi.org/10.1093/cz/zoab074

Martínez-Ruiz M, Arroyo-Rodríguez V, Arasa-Gisbert R, Hernández-Ruedas MA, San-José M (2024) Maintenance of different life stages of old-growth forest trees in deforested tropical landscapes. Ecology 105(4): e4273. https://doi.org/10.1002/ecy.4273

Mohd-Taib FS, Ishak SN, Mansor MS, Nor SM (2018) Impacts of Inundation on Bird Assemblages in Forests in and around a Hydrodam in Terengganu, Malaysia. Sains Malaysiana 47: 1645–1656. https://doi.org/10.17576/jsm-2018-4708-03

Mohd-Taib FS, Rabiatul AS, Nor SM (2014) Birds communities of fragmented forest within highly urbanized landscape in Kuala Lumpur, Malaysia. AIP Conference Proceedings 1614: 651–658. https://doi.org/10.1063/1.4895279

Nasruddin-Roshidi A, Mansor MS, Ismail NA, Ngadi E, Izzat-Husna M, Husin SM, Mohd-Taib FS, Illias R, Nor SM (2021) Recovery of bird communities following the

construction of a large-scale hydroelectric dam. Ecological Processes 10: 30. https://doi.org/10.1186/s13717-021-00298-1

Nordin N, Ismail NA, Khiruddin FZ, Daud UNS, Ali NBM, Shuhaily SHJ, Arazmi FN, Shah AKMK, Shukor A, Nor SM, Mansor MS (2025) Impacts of large-scale hydroelectric dam development on ground-dwelling birds revealed by long-term camera trapping. Ecological Processes 14: 63. https://doi.org/10.1186/s13717-025-00631-y

Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'hara R, Solymos P, Stevens M, Szoecs E (2023) vegan: Community Ecology Package. R package version 2.6-4.

Puan CL, Davison G, Kim CL, Berryman A, Bradshaw C, Marlow T (2020) Birds of Malaysia: Covering Peninsular Malaysia, Malaysian Borneo and Singapore. Lynx.

R Development Core Team (2020) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Rahim A-KA, Puan CL, Muhammad Adam Mah ANM, Zakaria M, Jamaludin N, Wahaf N (2025) Bioacoustic Assessment of Mangrove Health: Influence of Habitat Characteristics on Bird Richness. Biotropica 57: e13427. https://doi.org/10.1111/btp.13427

Rajagopal T, Sonaimuthu K, Selvarani S, Ponmanickam P, Sekar M (2022) A survey on avifauna diversity in some selected localities in and around Madurai city. Ecology. Environmental Conservation 28: S207–S216. https://doi.org/10.53550/eec.2022.v28i08s.032

Razali NB, Mansor MS, Ismail NA, Patah PA, Husin SM, Hussein MSR, Nor SM (2022) The use of salt licks by birds in Peninsular Malaysia. Global Ecology and Conservation 38: e02210. https://doi.org/10.1016/j.gecco.2022.e02210

Robson C (2014) Field guide to the birds of South-East Asia. Bloosbury Publishing.

Roshidi AN, Mansor MS Shukor AMd, Nor SM (2020) Recovery of Bird Assemblages After Construction; Case Study in Puah Catchment, Hulu Terengganu, 431–437. https://doi.org/10.1007/978-981-15-1971-0_43

Šálek M, Kalinová K, Daňková R, Grill S, Żmihorski M (2021) Reduced diversity of farmland birds in homogenized agricultural landscape: A cross-border comparison over the former Iron Curtain. Agriculture, Ecosystems & Environment 321: 107628. https://doi.org/10.1016/j.agee.2021.107628

Santamaria-Rivero W, Leyequien E, Hernandez-Stefanoni JL, Wood P (2016) Influence of landscape structure and forest age on the richness and abundance of different bird feeding guilds and forest-dependent birds in a seasonal dry tropical forest of Yucatan, Mexico. Tropical Ecology 57: 313–332.

Tang L, Shao G, Piao Z, Dai L, Jenkins MA, Wang S, Wu G, Wu J, Zhao J (2010) Forest degradation deepens around and within protected areas in East Asia. Biological Conservation 143: 1295–1298. https://doi.org/10.1016/j.biocon.2010.01.024

Tripathy S, Bandopadhyay A, Lenka R (2023) Avian species diversity in three major forest types in part of northern Eastern Ghats, Odisha, India. Ornithology Research 31: 207–220. https://doi.org/10.1007/s43388-023-00137-1

Tuen AA, Sapian AF, Ismail K, Peter C, Haba MHAH, Lee CIC (2018) Avifauna in Logged-Over Forest of Upper Baleh, Sarawak. Borneo Journal of Resource Science and Technology 8(2): 66–74. https://doi.org/10.33736/bjrst.1197.2018

Wee SQW, Teo JJH, Teepol B, Jelembai HNI, Au NJ, Yeap CA, Jain A (2024) Identifying Important Hornbill Landscapes in Sarawak, Malaysia. Global Ecology and Conservation 50: e02828. https://doi.org/10.1016/j.gecco.2024.e02828

Wegner B, Wolter C (2024) Mixed responses to paddling frequency of a bird community dominated by terrestrial species in a paddling tourism hotspot. Journal for Nature Conservation 80: 126636. https://doi.org/10.1016/j.jnc.2024.126636

Yahya MS, Atikah SN, Mukri I, Oon A, Hawa A, Sanusi R, Norhisham AR, Lechner AM, Azhar B (2023) Potential of agroforestry orchards as a conservation set-aside initiative in industrial rubber tree and oil palm plantations for avian biodiversity. Biodiversity and Conservation 32: 2101–2125. https://doi.org/10.1007/s10531-023-02594-y

Yang L, Xu H, Pan S, Chen W, Zeng J (2024) Identifying the impact of global human activities expansion on natural habitats. Journal of Cleaner Production 434: 140247. https://doi.org/10.1016/j.jclepro.2023.140247

Yap CAM, Sodhi NS (2004) Southeast Asian invasive birds: Ecology, impact and management. Ornithological Science 3: 57–67. https://doi.org/10.2326/osj.3.57

Zainol N, Roshidi AN, Husin SM, Shukor AM, Ilias R, Nor SM (2020) Impact of Forest Isolation on Mammals Diversity and Distribution Due to Impoundment of Hulu Terengganu Hydroelectric Project, Terengganu, Peninsular Malaysia. Water Resources Development and Management. Springer, 468–478. https://doi.org/10.1007/978-981-15-1971-0_47

Supplementary material 1

Forest patches as critical habitats for birds in Malaysian hydroelectric project areas

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Data type: xlsx

Explanation note: This dataset lists bird species observed across different habitat types in Malaysia, specifically in recently disturbed forests (RD), agricultural forest patches (AFP), and mosaic habitats (MH). It includes details such as the bird's family, scientific and common names, the number of individuals recorded at six different sites, their forest dependency (whether they rely on forests or not), IUCN conservation status (e.g., Least Concern), and feeding guilds like carnivores. The data helps show which birds are present in each habitat and how they relate to forest conditions and conservation priorities.

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